DESI Overview

Michael Levi (LBNL)
DESI Project Director

Outline follows Questions

We are asking projects to focus on the following in their presentations:

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4) estimate of the number of physicists (in FTEs) needed by project phase, including operations and data analysis.

5) anything you wish to reinforce from, or add to, Snowmass findings about this project, and anything else you would like to communicate to P5?

Project Scope

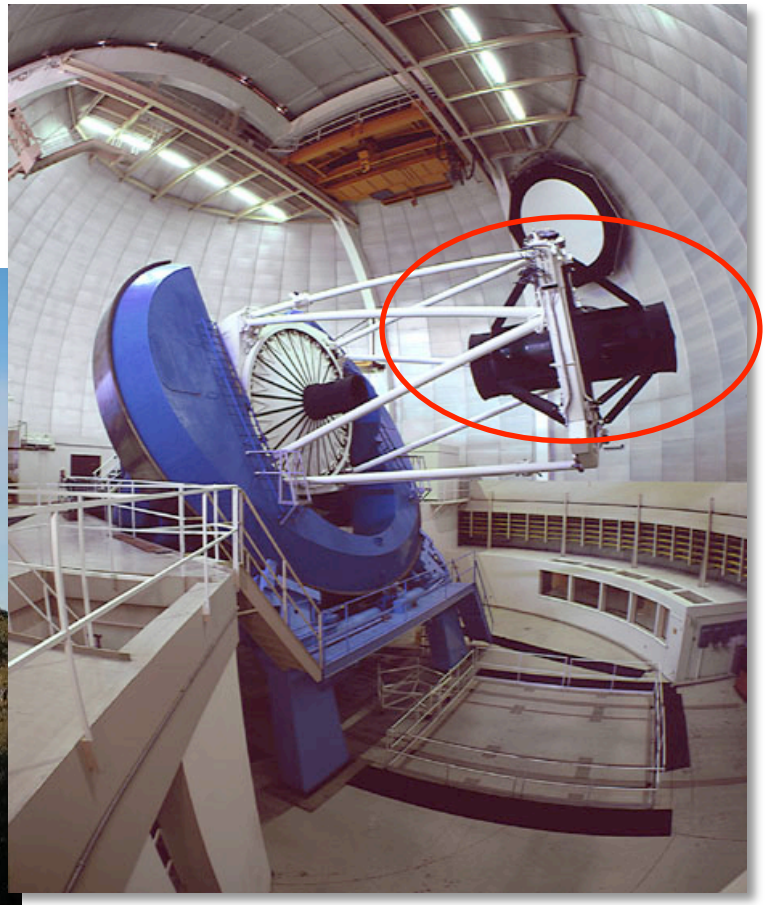
- **MS-DESI is the Mid-Scale Dark Energy Spectroscopic Instrument (DESI for short)**

- **Pioneering Stage-IV Dark Energy Experiment**
  - **CD0 issued in September 2012 for Stage IV baryon acoustic oscillation (BAO) experiment – standard ruler to measure dark energy**
  - **should fill the gap in time between DES and LSST and uses complementary method based on spectroscopy instead of imaging**

- **DESI meets this goal**
  - **scientifically ambitious enough to satisfy Stage IV criteria**
  - **At least *x10* more volume than BOSS (Stage III, will complete in 2014)**
  - **technically advanced enough to be ready on 2018 time frame**
  - **will be statistically limited; BAO is a proven robust technique**
  - **rich scientific program: DE, inflation, neutrino mass, test GR**

Mayall 4m Telescope

- DESI will be installed at the Mayall Telescope on Kitt Peak, AZ
- Kitt Peak is operated by NOAO for the NSF
- Mayall Telescope was built in 1973, NSF wants to divest => opportunity



corrector

DESI Conceptual Design

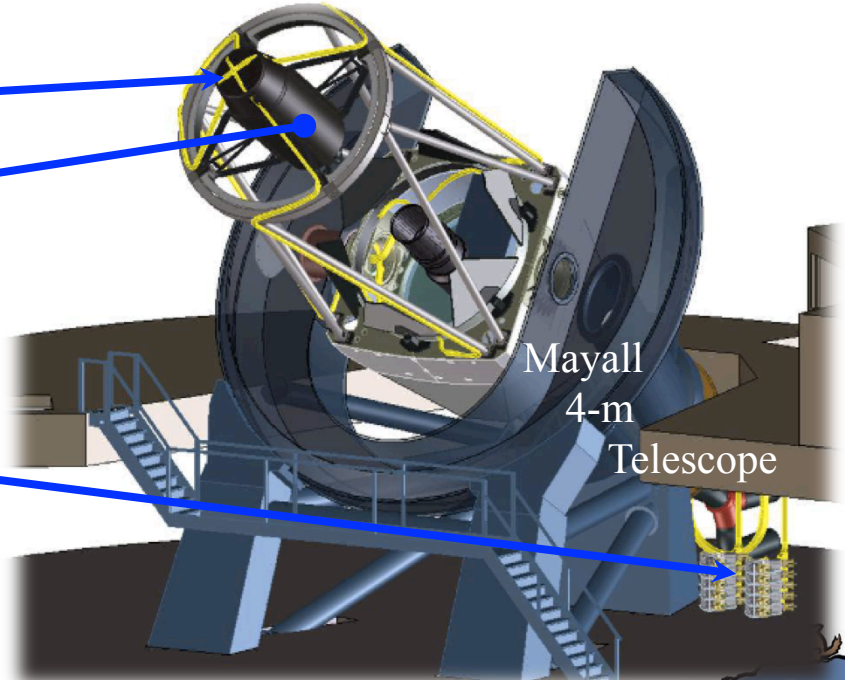
- Scale up BOSS to a massively parallel fiber-fed spectrometer with 5x more fibers, larger telescope aperture, robotic fiber positioners
- Stage-IV BAO over a broad redshift range: $0.5 < z < 1.6$, $2.2 < z < 3.5$
- Sky area: 14,000 square degrees
- Number of galaxy redshifts: 30 million
- Medium resolution spectroscopy, R ~ up to 5500

Three main hardware components:

5000 fiber actuators

New 8 deg^2 field-of-view corrector
DES heritage

10 New spectrographs
BOSS heritage



DESI Timeline

- **Recent community reports: "Rocky-III"**
  - ***"There is compelling case for an advanced wide-field spectroscopic survey, which would enable dark-energy information at the Stage IV level through the techniques of Baryon Acoustic Oscillations and Redshift Space Distortions"***
- **Recent community reports: Snowmass**
  - ***"the community strongly supports continuing the program of Stage III and Stage IV dark energy experiments, and moving forward as quickly as possible with the construction of LSST and DESI."* Snowmass CF5, arXiv:1309.5386(2013).**
- **CD-0, "Approve Mission Need" was approved Sept. 2012**
- **Two projects, BigBOSS & DESpec, proposed to do BAO spectroscopic survey. LBNL named lead lab in Dec. 2012**
- **Director's Review for CD-1 just happened**
- **Lehman CD-1 review planned for February, 2014**

Timeline

- **Deconstruction of Mayall begins: October 2017**
- **Installation of corrector begins: February 2018**
- **Commissioning begins: October 2018**

Milestone	Milestone Title	Schedule Date
CD-0	Approve Mission Need	09/30/12 (A)
CD-1	Approve Alternative Selection and Cost Range	Q2 FY 2014
CD-2	Approve Performance Baseline	Q1 FY 2015
CD-3a	Approve Start of Construction (Long-Leads)	Q1 FY 2015
CD-3b	Approve State of Construction	Q4 FY 2015
CD-4	Approve Project Completion	Q4 FY 2019

Timeline to Results

DESI is the experiment that can deliver stage IV results by 2020

BOSS delivering results 2.5 years from start (w/ 1.5 yrs data)

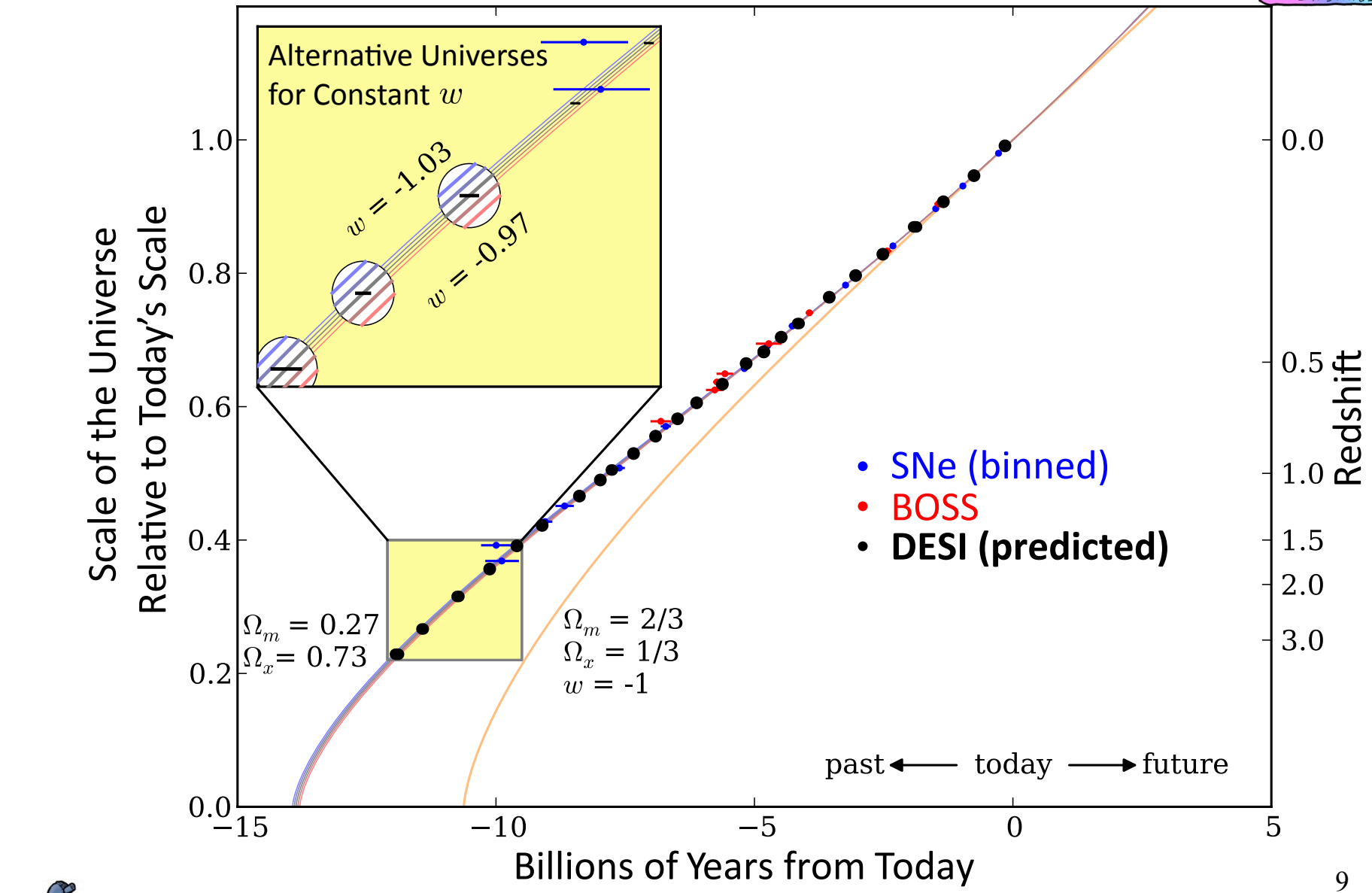
Sep 2009 Commissioning
Dec 2009 Survey start
July 2011 1rst Data set defined
Jan 2012 BAO results
Dec 2013 BAO results with 90% of data

DESI to deliver results <2 years from start (w/ 1 yr data)

Oct 2018 Commissioning / pilot observations
April 2019 Survey start
April 2020 1rst Data set defined
Nov 2020 BAO results on 1rst year data
Nov 2022 BAO results with 60% of data, surpasses science requirements

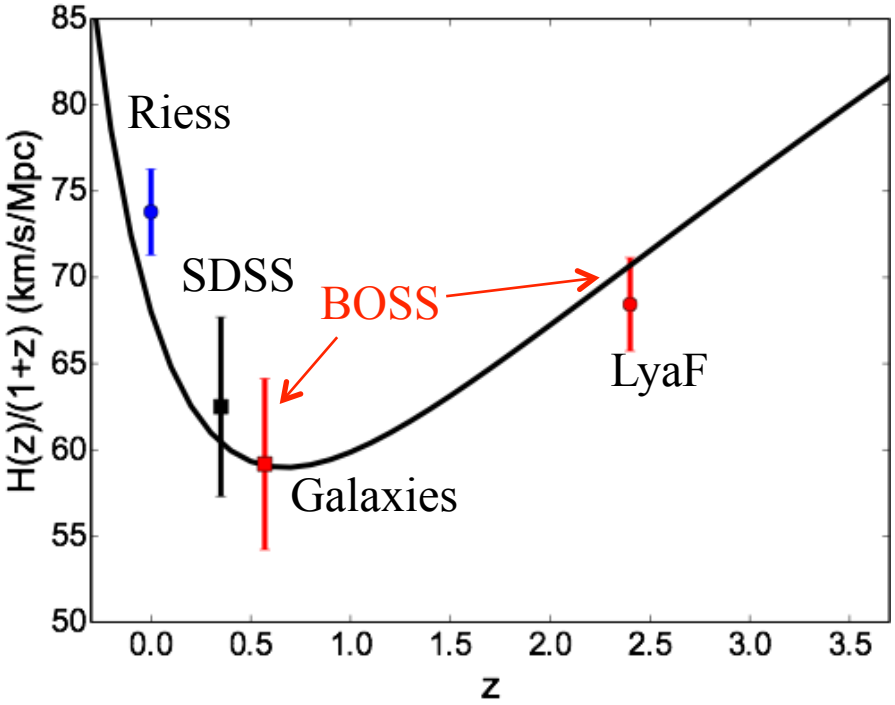
April 2024 Survey ends, final BAO results 6 mo. later, final PS a bit later.

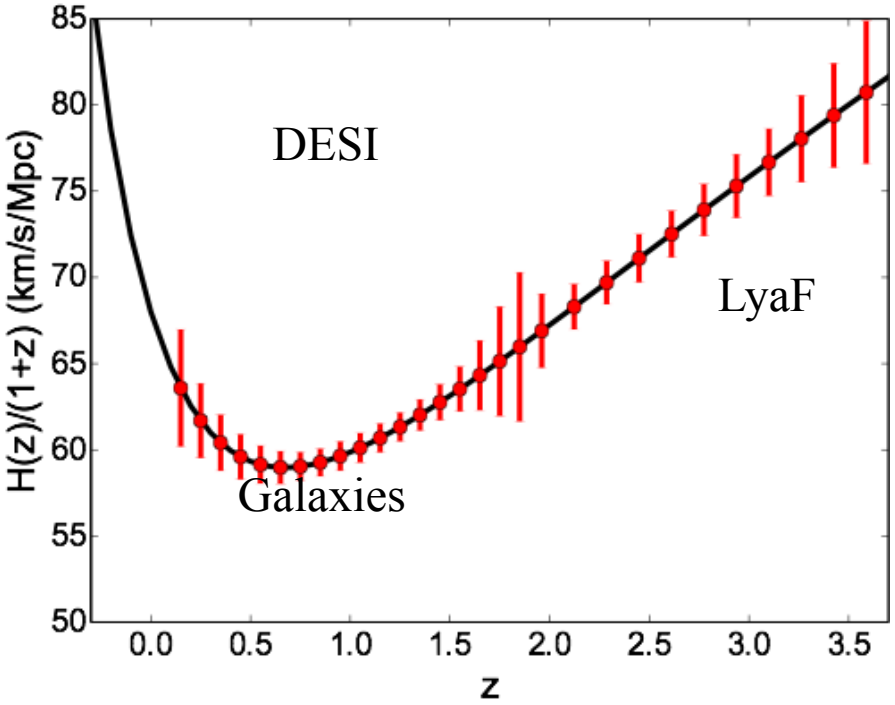
DESI Will Discriminate Between Dark Energy Models



BAO-measured Hubble parameter

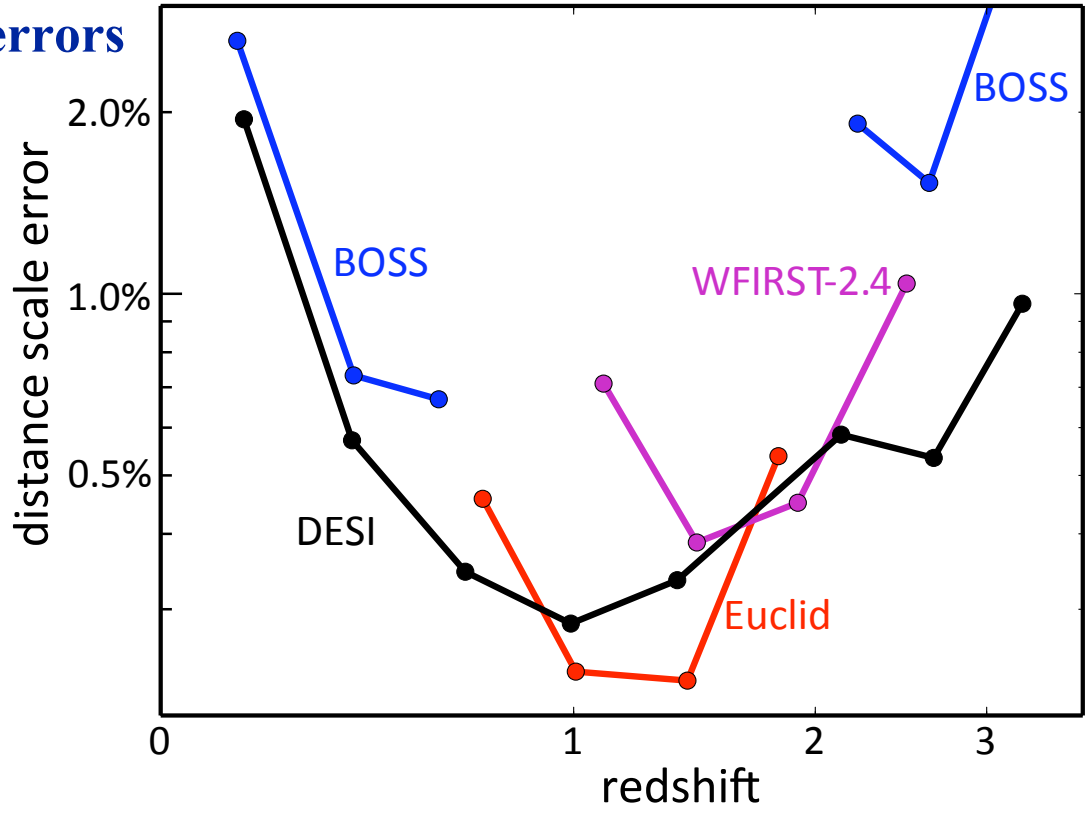
Will provide a unique history of the expansion of the Universe to unprecedented accuracy



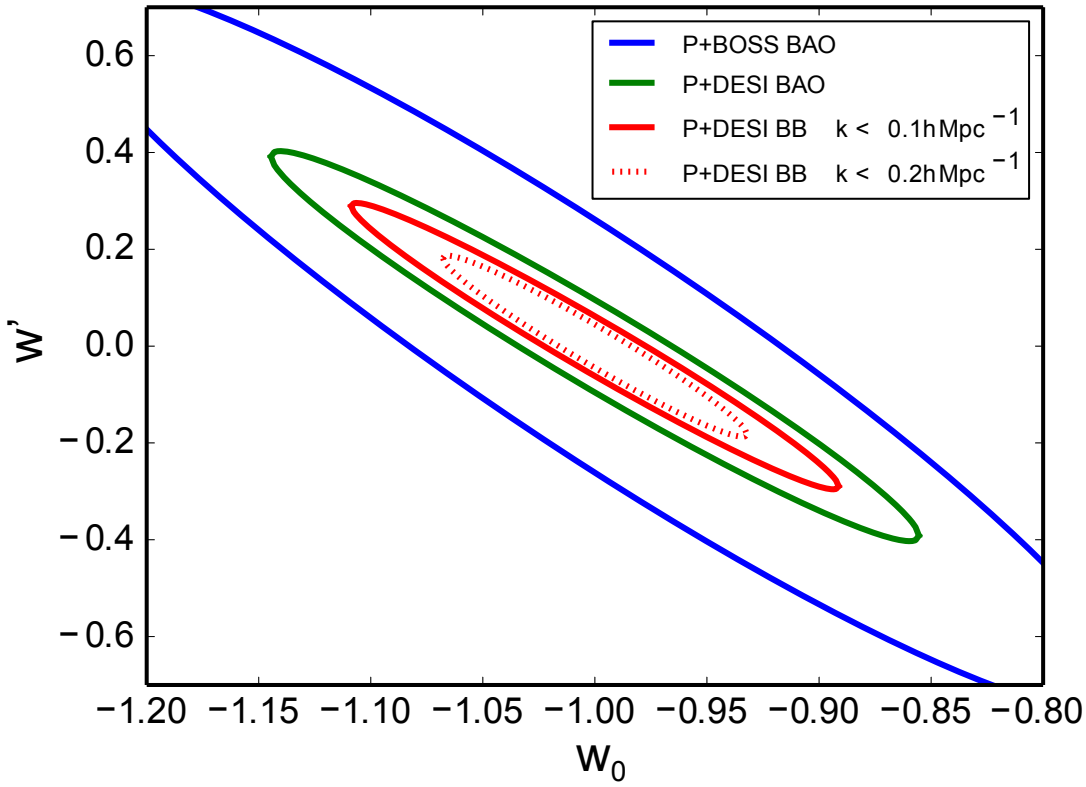


Unique Capabilities of DESI

- **DESI will be a substantial step forward in precision.**
  - **10-fold more inverse variance on $D_V(z)$ than BOSS, low risk.**
- **DESI is close to the ultimate "easy" ground-based optical BAO experiment.**
  - **We expect to be competitive with Euclid and extending to higher *z***
  - **Low systematic errors**



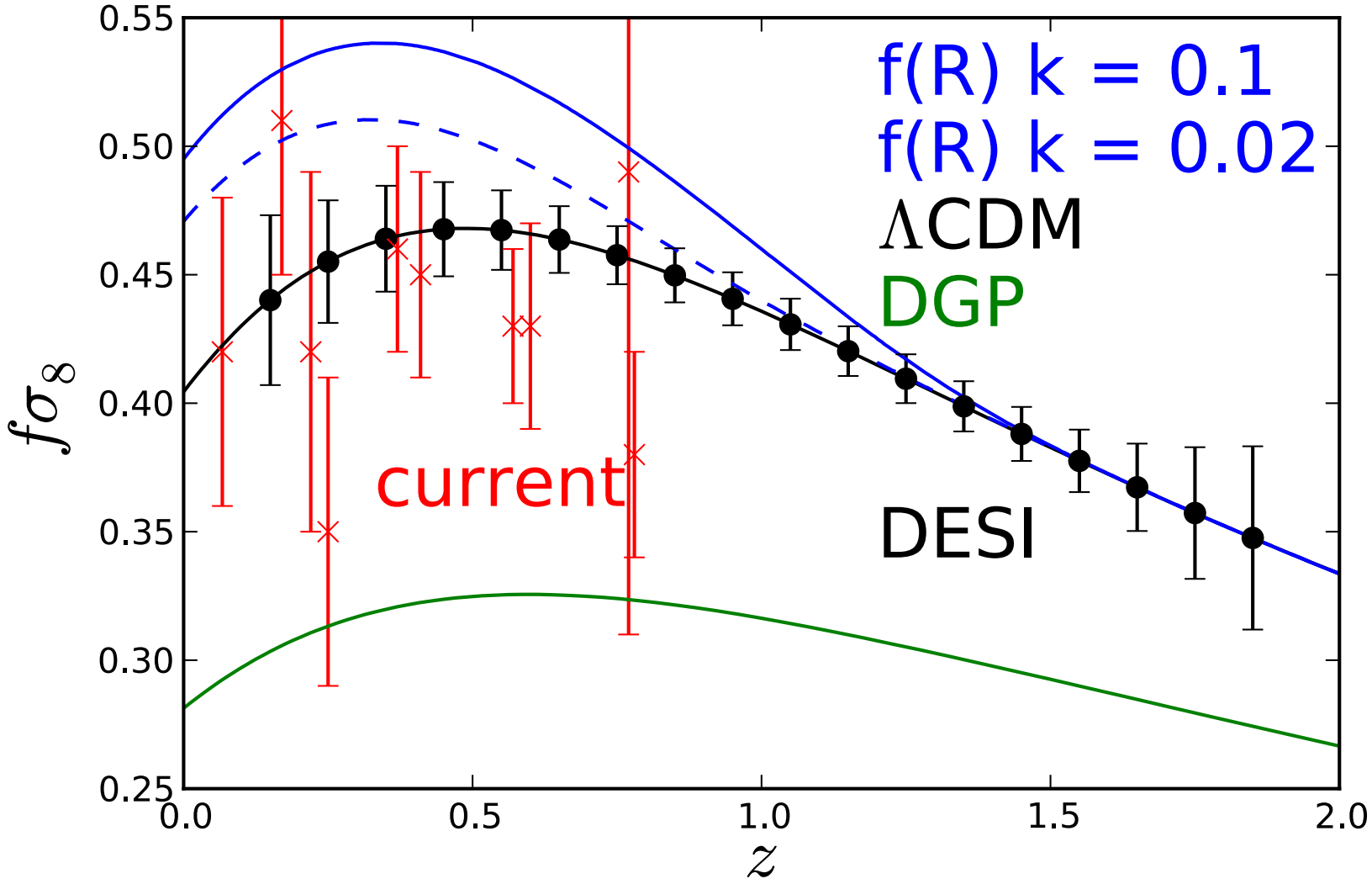
DESI is a Stage IV DE Experiment



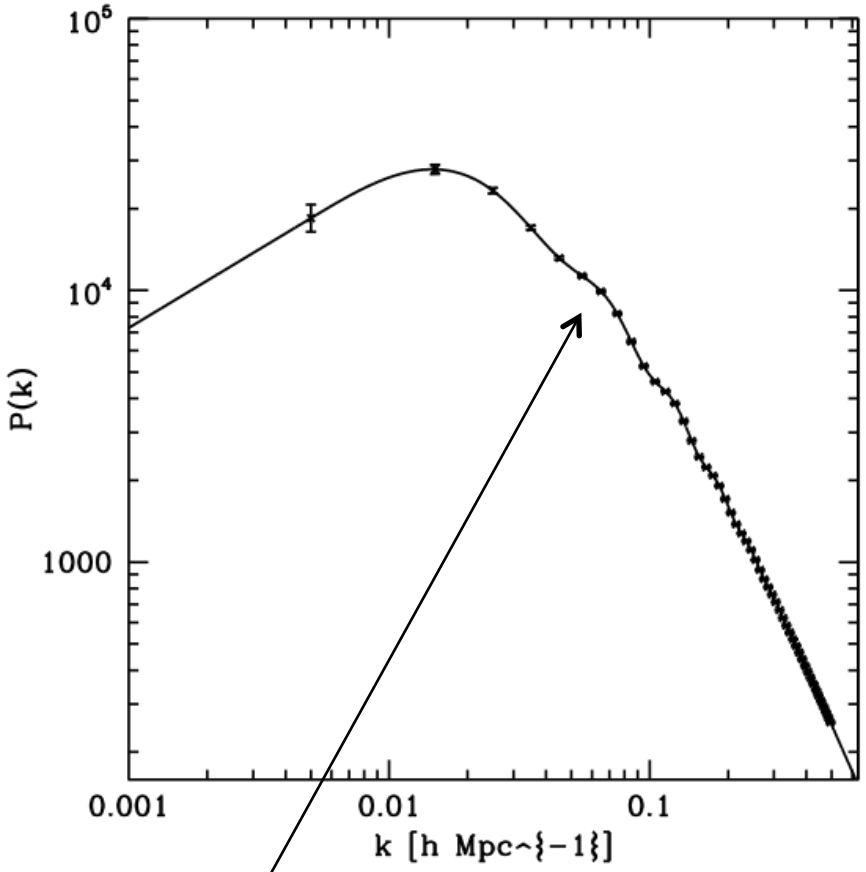
Surveys	FoM	a_p	σ_{w_p}	σ_{Ω_k}
BOSS BAO	37	0.65	0.055	0.0026
DESI galaxy BAO	128	0.71	0.023	0.0013
DESI galaxy and Ly-α forest BAO	166	0.73	0.023	0.0010
DESI BAO + gal. broadband to $k < 0.1\ h\,\mathrm{Mpc}^{-1}$	342	0.75	0.015	0.0008
DESI BAO + gal. broadband to $k < 0.2\ h\,\mathrm{Mpc}^{-1}$	756	0.74	0.011	0.0007

DESI can distinguish MG from DE

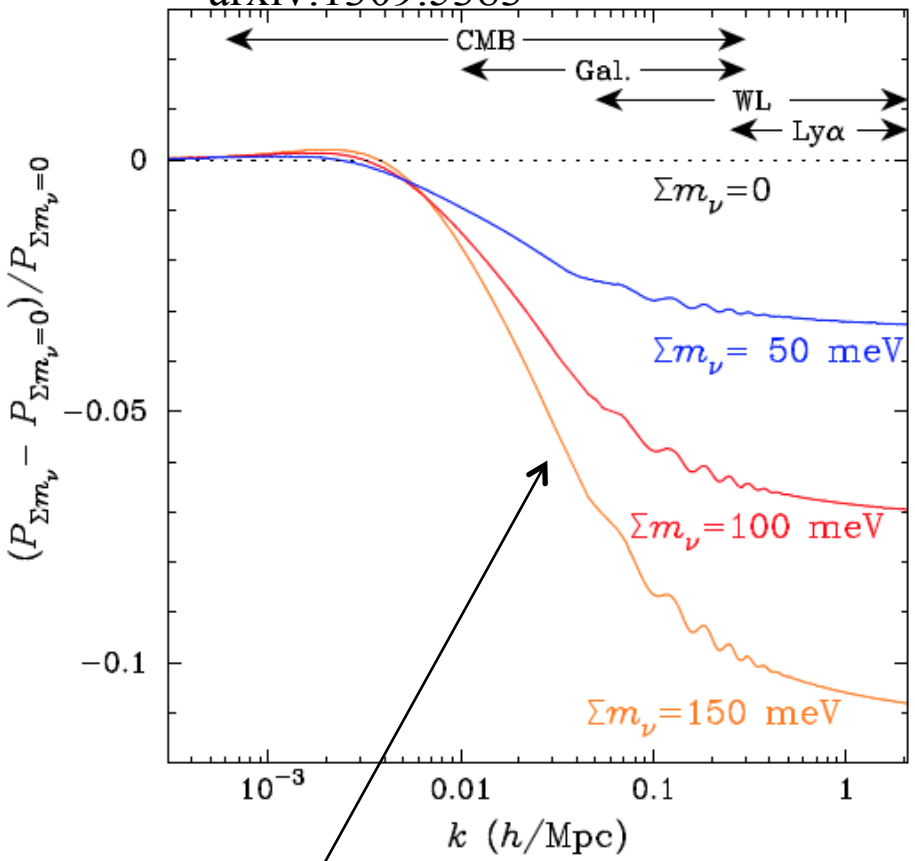
DESI will measure the growth of structure



Very precise power measurement



arxiv:1309.5383

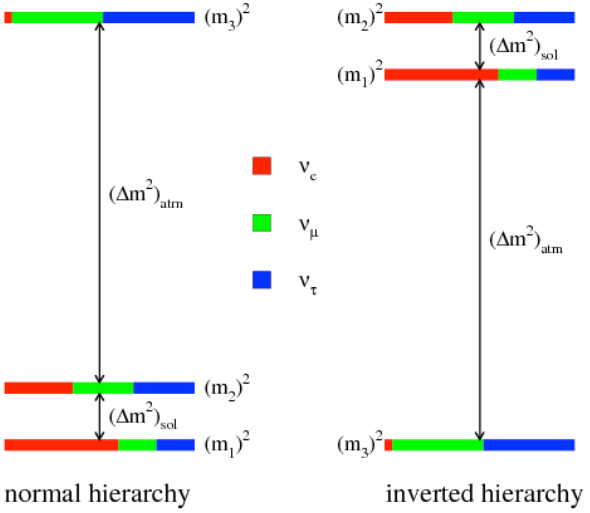


- **The position of the BAO wiggles is the standard ruler we use to measure distance scale**
- **Using the full power spectrum we can extract add'l information (eg. neutrino mass)**

DESI measures $\sum m_\nu$

… and if we're fortunate, the neutrino hierarchy as well.

- The shape of the power spectrum encodes information about neutrino masses. Massive neutrinos suppress cosmic structure growth
- Minimum total mass:
  - normal: 0.057 eV
  - inverted: 0.096 eV



Data	$\sigma_{\sum m_\nu}$ [eV]	
Planck	0.350	
Planck+DESI BAO	0.090	
+Gal ($k_{max} = 0.1$)	0.024	conservative
+Gal ($k_{max} = 0.2$)	0.017	optimistic

Constraining Dark Radiation

Constraints on extra relativistic energy density (conventionally measured in units of effective massless neutrino species) can be improved significantly over Planck

Data	$\sigma_{N_{\nu,\mathrm{eff}}}$
Planck	0.18
Planck+DESI BAO	0.18
+Ly-α forest + Gal ($k_{\mathrm{max}} = 0.2$)	0.063

Measuring the Inflationary Spectral Index

Galaxy broadband measurements can substantially improve the n_s measurement over Planck alone.

Data	σ_{n_s}	σ_{α_s}
Gal ($k_{\max} = 0.1$ h^{-1}Mpc)	0.0024 (1.6)	0.0051 (1.1)
Gal ($k_{\max} = 0.2$ h^{-1}Mpc)	0.0022 (1.7)	0.0040 (1.3)
Ly-α forest	0.0029 (1.3)	0.0027 (2.0)
Ly-α forest + Gal ($k_{\max} = 0.2$)	0.0019 (2.0)	0.0020 (2.7)

$$P_{\rm primordial}(k) \propto (k/k_0)^{n_s + \frac{1}{2}\alpha_s \ln(k/k_0)}$$

(relative improvement over Planck alone)

Questions

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DESI Expert Collaboration

Partners are experienced

AAO, USTC, +Spain: Fiber positioners

FMOS, LAMOST fiber positioners

IAA (Spain): Focal plane

GTC Nasmyth mount + positioner design

Fermilab (U.S.): Telescope top-end + lens cell

w/ UCL (U.K.): Telescope optics

Dark Energy Survey top-end + optics

Durham: Fibers + testing

FMOS + Fibers for physics exp'ts

LAM + CPPM (France): Spectrographs

VIMOS spectrographs

CEA (France): Cryo systems

Megacam cryo

Berkeley Lab (U.S.): CCDs + electronics, optical design, project management

WFIRST/JDEM optical design

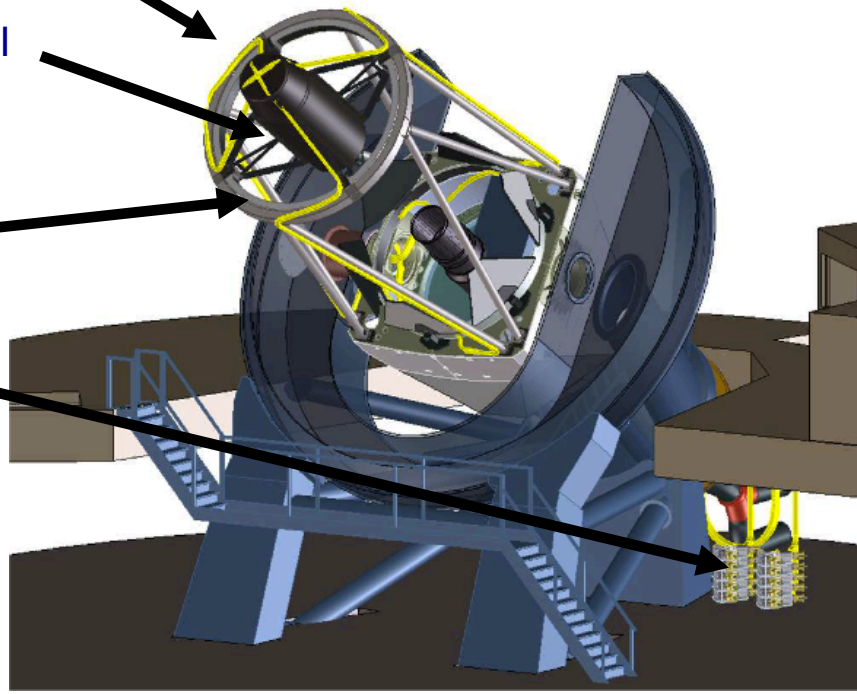
DES, BOSS, JDEM detectors

Yale: fiber view camera */QUEST*

U Michigan: calibration hardware */DES*

SLAC, Ohio State: data acquisition + guiding *BOSS, DES, LSST*

NOAO: telescope interface, operations *DECam*



Institutional Agreements

DESI Agreements:

- —**UK STFC Funding, finished proposal selection ($4.5M)**
  - "I am happy to assure you that the likelihood of STFC support is high and would be happy for you to make your DESI partners aware of this current status." C. Vincent, Head of Astronomy Division, STFC
- —**AAO, China, Swiss down-select to provide fiber robots**
- —**Spain, Letter from Ministry**
- —**France, Director of CEA/Saclay for Cryostats**
- —**U. Arizona, Stewart Obs. for target selection dataset**
- —**SJTU, SHAO, letter from institutions for data processing**
- —**$2.1M Grant from Gordon & Betty Moore Foundation**
- —**42 letters of interest from institutions**

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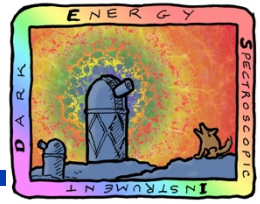
DESI Proposed DOE Budget Profile



- Just finished Directors Review for CD-1, CD-1 review in February 2014
- Base cost comes directly from the resource loaded schedule (2500 lines)
- Assumes $12M from foreign sources & $5M from domestic non-DOE
- Includes 48% contingency (based on formal analysis)
- R&D has been completed

Then Year $K						
	FY14	FY15	FY16	FY17	FY18	TOTAL
Labor	3,050	4,100	4,500	2,600	500	14,750
Materials	150	2,900	5,100	5,300	100	13,550
Total Base	**3,200**	**7,000**	**9,600**	**7,900**	**600**	**28,300**
Contingency	200	1,500	4,600	6,300	1,100	13,700
Grand Total	**3,400**	**8,500**	**14,200**	**14,200**	**1,700**	**42,000**

Multi-Agency: DOE/NSF

- **Jan 2013: DOE/NSF signed Statement of Principles**
- **May 2013: DOE requested Mayall site from NSF as the preferred site**
- **NSF may provide bridge funding for Mayall through 2017 to maintain telescope and operations**
- **DOE would be responsible for operating costs of Mayall telescope for DE research after 2018**

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U.S. Institutions

- Argonne National Laboratory
- University of Arizona
- Brookhaven National Laboratory
- University of Calif, Berkeley
- University of Calif, Irvine
- University of Calif, Santa Cruz
- Carnegie Mellon University
- Cornell University
- Fermi National Accelerator Lab
- Harvard University
- University of Kansas
- Kansas State University
- Lawrence Berkeley National Lab
- University of Michigan
- Michigan State University
- National Optical Astronomy Obs.
- New York University
- The Ohio State University
- University of Pittsburgh
- Siena College
- Southern Methodist University
- SLAC National Accelerator Lab
- Texas A&M University
- University of Utah
- Washington University at St. Louis
- University of Wyoming
- Yale University

180 Collaborators

… 21 US Universities

… 5 DOE Laboratories

… 19 foreign institutions

4 DOE Early Career Awardees

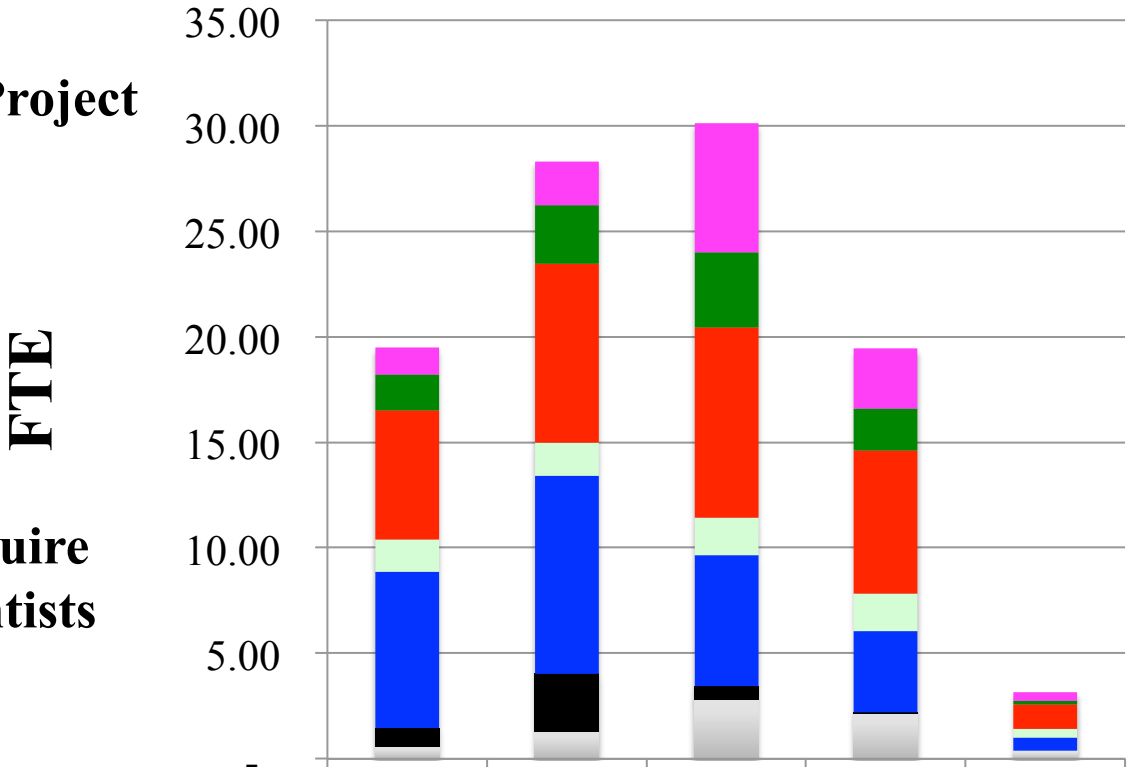
DESI Collaboration

- **July collaboration 4-day meeting, 100 talks, 115 attendees**

US FTE Profile by Labor Category

Chart is for Construction Project

During Operations will require ~25-40 FTE active US scientists



	2014	2015	2016	2017	2018
Technical	1.28	2.08	6.12	2.85	0.43
Scientist - Costed	1.70	2.77	3.58	1.97	0.15
Scientist - Uncosted	6.10	8.50	9.00	6.80	1.19
Management	1.54	1.57	1.79	1.78	0.38
Engineer	7.41	9.37	6.19	3.83	0.63
Designer	0.87	2.72	0.62	0.07	-
Computing	0.58	1.30	2.82	2.14	0.39

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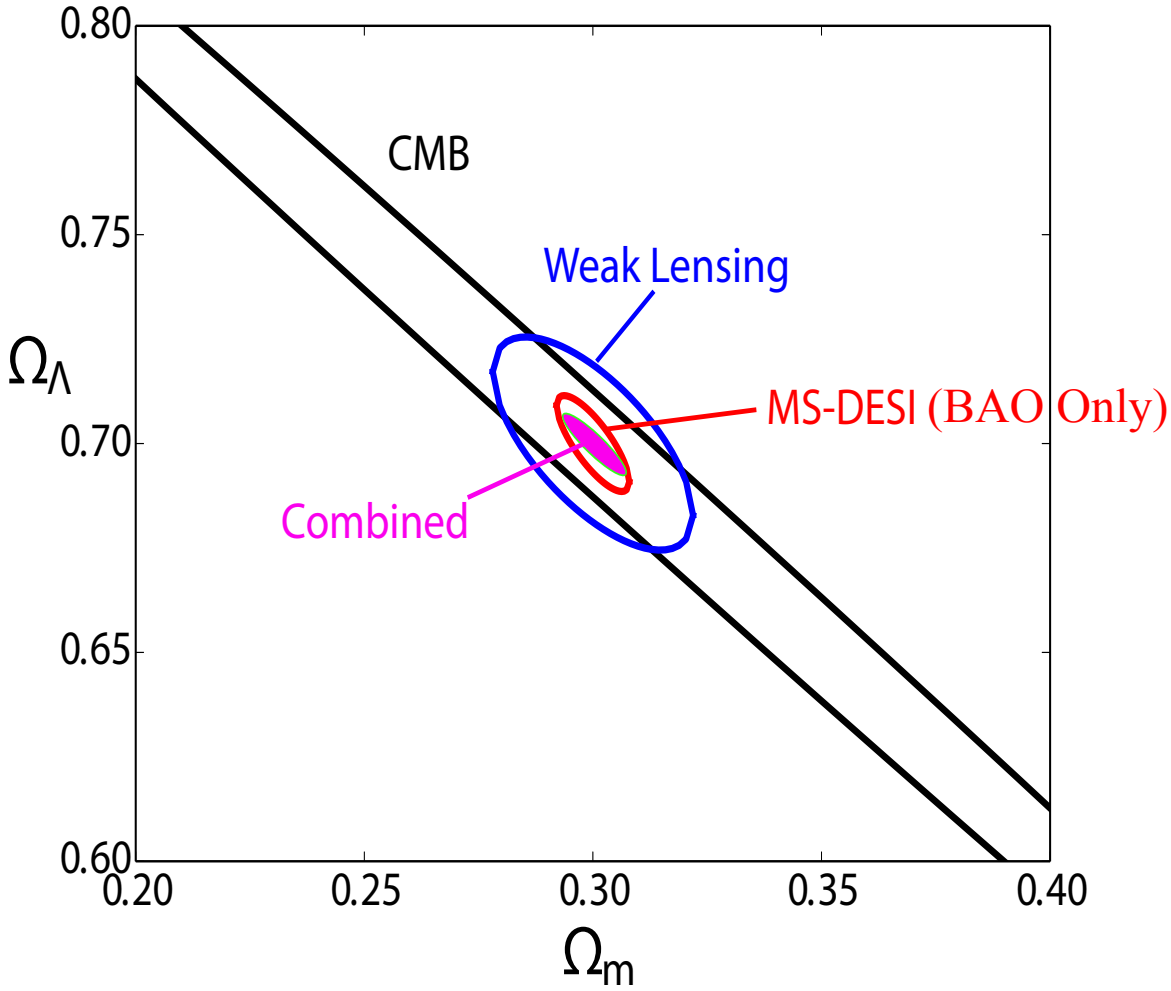
DESI complements other surveys

- **Overlap with WL surveys**
  - Systematics
  - Photo-z calibrations, source of largest sys. error
- **DESI very complementary to Euclid/WFIRST**
  - Wider redshift range
  - Different techniques to get at tracer populations
- **DESI complements SN surveys**
  - Wide redshift coverage overlaps range
- **DESI complements CMB surveys**
  - DESI needs Planck to calibrate the BAO scale
  - CMB Stage-IV needs DESI to achieve their neutrino mass constraints

Combining DESI and LSST

Results further improved in combination:



Broad Scientific Program: Advances in Dark Energy, Neutrino Physics, Inflation

Dark Energy Tests:	
Distance Scale	$R(z):\pm 0.16\%,(0<z<3.7)$
Hubble Parameter	$H(z):\pm 0.5\%,(0<z<1.6)$
Modified Gravity	$f\sigma_8:\pm 0.35\%,(0<z<1.6)$
DE Equation of State	$w_p:\pm 0.011$
DETF Figure of Merit	$\mathrm{FOM}:756$
Power Spectrum Test:	
Inflation	$n_s:\pm 0.0019$
Inflation	$\alpha_s:\pm 0.0020$
Neutrino Mass	$\Sigma m_\nu:\pm 0.017\,\mathrm{eV}$
Number of neutrinos	$\Sigma \mathrm{N}_\nu:\pm 0.063$

Summary

- **Science: High value robust science**
  - **Stage-IV Dark Energy experiment based on low risk, low systematics, mature method. Will provide a detailed history of the expansion of the Universe**
  - **Sum of neutrino masses to 0.017 eV**
  - **Complementary to LSST and DES**
- **DESI has extensive heritage, low risk**
  - **Experiment based on proven techniques – hardware & software**
  - **Collaboration is world-class in BAO science, includes experts from BOSS and DES, and in the key technologies, continuing to expand in depth and breadth**
  - **Bottom-up cost, Directors review done, CD-1 review in two months**
- **Broad participation**
  - **Extensive foreign participation and funding**
  - **Broad US base including many early career awardees**

END

Review Committee

Lowell A Klaisner, Chairperson

Management Subcommittee
- William Edwards
- Gil Gilchriese, Chairperson
- Steve Kahn

Science Subcommittee
- Roc Cutri
- Olivier P. Dore
- Lloyd Knox, Chairperson
- Craig Tull
- J. Xavier Prochaska

Corrector and Optics Subcommittee
- Rebecca Bernstein
- Scott Olivier, Chairperson

Instrument Subcommittee
- Bruce Bigelow
- Chuck Claver, Chairperson

- **The Committee congratulates the Project Team for the excellent work that has been done for this review and the design to date.**

- **In the view of this Committee the team will be ready for the CD-1 Review.**

Science – Findings

- The BAO technique is now a mature dark energy probe, with demonstrably small systematic effects. The BOSS survey has measured the BAO feature in the galaxies and the Lyman-alpha forest with high significance, and is yielding high precision distance measurements.
- The DESI survey, with objective KPPS, represents an order-of-magnitude improvement over the current state of the art both in the effective volume of the survey and the inverse variance of the distance measurements.
- With appropriately-revised threshold KPPs, DESI is a Stage IV dark energy survey based on just the galaxy-based BAO technique.
- The DESI survey will yield precise measurements of the growth of structure through the redshift space distortion (RSD) technique, providing complementary information about the cause of acceleration.
- Use of the broad-band information in the galaxy correlations potentially leads to large increases in the FoM. The systematic effects are less certain here.
- The DESI team is building on the strong heritage of BOSS. Reliance upon the experience, expertise, and software design of previous experiments is a recurrent theme.

Gordon and Betty Moore Foundation

$2.1M Grant from Gordon and Betty Moore Foundation

- For unit #1 (of ten) spectrograph
- For hardest corrector glass element(s)

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A big boost to BigBOSS

$2.1 Million Grant to Berkeley Center for Cosmological Physics advances dark energy research at UC Berkeley and Berkeley Lab

Dec. 4, 2012

Berkeley, Calif. – A $2.1 million grant from the Gordon and Betty Moore Foundation to the University of California at Berkeley, through the Berkeley Center for Cosmological Physics (BCCP), will fund the development of revolutionary technologies for BigBOSS, a project now in the proposal stage designed to study dark energy with unprecedented precision. BigBOSS is based at the U.S. Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab).

"BigBOSS is the next big thing in cosmology," says Uroš Seljak, Director of the BCCP, who is a professor of physics and astronomy at UC Berkeley and a member of Berkeley Lab's Physics Division. "It would map millions and millions of galaxies, allowing us to measure dark energy to high precision – and would yield other important scientific results as well, including determining neutrino mass and the number of neutrino families."

Dark energy is the unknown something that appears to account for almost three-quarters of the mass-energy of the universe and is the cause of its accelerating expansion. The discovery of the accelerating universe, announced in 1998 by two teams, resulted in the 2011 Nobel Prize in Physics, divided between Berkeley Lab and UC Berkeley astrophysicist Saul Perlmutter, leader of the Supernova Cosmology Project, and Brian Schmidt and Adam Riess of the competing High-z Supernova Search team.